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Above-ground biomass, nutrients, and persistence of an early and a late maturing Mucuna variety in the Forest–Savannah Transitional Zone of Ghana

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Abstract

Many farmers in West Africa have adopted the herbaceous legume, *Mucuna pruriens*, as a fallow species to control weeds and to increase soil fertility on crop lands. This paper presents the biomass, nutrient content, and persistence results of farmer managed trials with late maturing *M. pruriens* var. *utilis* (L.) D.C. and an early maturing unclassified Mucuna cultivar relative to a short season natural fallow (control). From August until December 1998 and from June 1999 until March 2000, research was conducted at different farm locations in the Forest–Savannah Transitional Zone and in the Guinea Savannah Zone of Ghana. The following parameters were evaluated: (1) accumulation of above-ground Mucuna biomass during the short rainy season; (2) atmospheric N_2 fixation during the same period; (3) Mucuna seed yield components; (4) persistence of above-ground Mucuna and natural fallow biomass throughout the dry season; (5) nutrient concentration and nutrient accumulation of Mucuna and natural fallow at the beginning and the end of the dry season; and (6) percentage ground cover by various biomass components throughout the dry season. During the first 2 months of establishment, *M. pruriens* grew slowly, producing 163 kg ha^{-1} above-ground biomass after 30 days and 1472 kg ha^{-1} after 60 days, but produced 4003 kg dry matter ha^{-1} after 90 days. Atmospheric nitrogen (N_2) fixed by late maturing *M. pruriens* was estimated at 107.7 kg ha^{-1} but only 46.1 kg ha^{-1} for the early maturing Mucuna cultivar. The estimated amount of N_2 fixed was significantly correlated with the amount of Mucuna biomass produced with $R^2 = 0.75$ for the early maturing cultivar and $R^2 = 0.69$ for *M. pruriens*. The nutrient uptake of macronutrients other than N in the Mucuna fallow did not differ significantly from that of the natural fallow treatment for either cultivar. Following a linear regression model, total above-ground biomass on *M. pruriens* plots declined by 503 kg ha^{-1} every 4 weeks from November until March, while the biomass on plots planted with the early maturing Mucuna cultivar declined by 911 kg ha^{-1}. While ground coverage (including weeds and crop residues) on fields planted with *M. pruriens* was still 89.7% at the end of the dry season, coverage on fields planted with the early maturing *Mucuna* variety averaged only 72%.

It was concluded that late maturing Mucuna varieties planted as a relay intercrop in maize (*Zea mays*) in June can be more easily integrated into existing farming systems than early maturing ones planted in August/September because Mucuna planting does not compete with other farming activities but can be combined with the second weeding of maize. Moreover, it is suggested

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that the major advantage of a Mucuna fallow is based on the option of not having to burn vegetation in preparation for the next cropping season. The few emerging weeds can be easily slashed as compared to a natural fallow which produces large amounts of lignified plant material. Therefore, this slash-and-mulch technology leads to reduced nutrient losses.

Keywords: Cover crop; Fallow; Biomass; N_2 fixation; Nutrient uptake; Ground cover

1. Introduction

Reduced fallow periods have led to a decline of soil fertility restoration in traditional bush fallow systems in many parts of West Africa (Pieri, 1992; Amanor, 1996). The use of mineral fertilizers drastically declined after the removal of subsidies on agricultural inputs in Ghana (Donovan and Casey, 1998) and fertilizers are now beyond the economic reach of many small-scale farmers. *Chromolaena odorata* (L.) R.M. King and Robinson, the dominant fallow species in the Forest–Savannah Transitional Zone of Ghana, and grassy Savannah species encroaching from the north are proving difficult for farmers to control (Amanor, 1996) and constraining agricultural productivity.

It appears that these conditions are what have led to an increase in smallholder adoption of Mucuna fallow technologies in some areas of the Forest–Savannah Transitional Zone of Ghana (Anthofer, 2000; Gregory and Mensah, 2000). Mucuna has the potential to contribute to soil N and increase the yields of subsequent crops through symbiotic N_2 fixation (Houngnandan et al., 2000). At the same time, Mucuna helps to control weeds (Versteeg and Koudokpon, 1990; Udensi et al., 1999; Akobundu et al., 2000).

1.1. Mucuna biomass production and N accumulation

Many green manure legumes have a high N accumulation capacity (80–100 kg ha^{-1} 45–60 days after planting) of which the major portion is derived from biological N_2 fixation (Becker et al., 1995). Estimates of the amounts of N derived from atmosphere (NdA) of Mucuna spp. worldwide range from 20 to >200 kg ha^{-1} (Carsky, 1989; Van Noordwijk et al., 1995; Sanginga et al., 1996; Becker and Johnson, 1998). Carsky et al. (1998), reported that most of these estimates are deduced from researcher managed trials.

Several studies have estimated the biomass production of Mucuna-improved minor season fallows, considering it to be a parameter for subsequent crop performance. Improvement in crop yield has been shown to be highly correlated with the amount of biomass produced and the total N accumulated by the previous leguminous crop (Schulz et al., 1999; Fosu, 1999; Houngnandan, 2000). In the northern Guinea Savannah of Nigeria, *Mucuna cochinchinensis* (Lour.) A. Cheval produced 6170 kg dry matter ha^{-1} in Kaduna (190 days growing season) and 3370 kg ha^{-1} in Bauchi (150 days growing season) while N accumulation was 154 and 85 kg ha^{-1}, respectively (Carsky et al., 1999). In the Guinean Savannah Zone of northern Ghana, *M. pruriens* produced 8400–9800 kg ha^{-1} of dry matter with a N content of 155–206 kg ha^{-1} (Fosu, 1999). In the derived Savannah of Benin, Mucuna dry weight in farmer's fields was found to be 3770–4820 kg ha^{-1} at 20 weeks after planting (Houngnandan, 2000).

1.2. Persistence and degradation of accumulated biomass in the dry season

After the senescence of a Mucuna cover crop with the onset of the dry season around November/December in West Africa (Fig. 1), not all the biomass

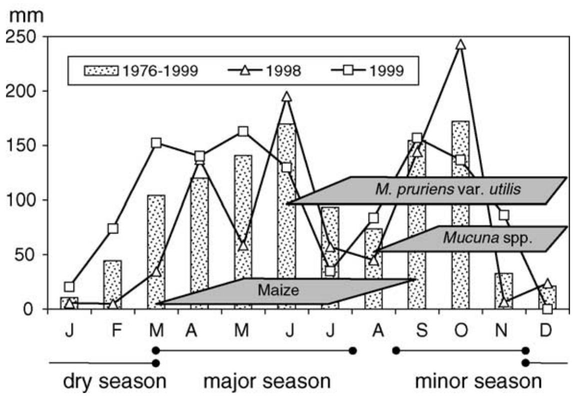

Fig. 1. Maize/Mucuna cropping systems and monthly average rainfall in Sunyani district.

built up can be expected to persist until the next cropping season several months later (Carsky and Eteka, 2000). Occasional rains during the dry season can lead to an accelerated decomposition of biomass and leaching of nutrients. Heavy winds commonly observed towards the end of the dry season (Kwasi, 1998) can carry away some of the biomass and thus contribute to further losses, while harvest of Mucuna seeds in January/February also drastically reduces the total amount of biomass left in the field. Furthermore, bushfires and uncontrolled livestock grazing can result in a complete loss of biomass. It was observed in the Forest–Savannah Transitional Zone (De Vleeschauwer et al., 1980) and in the Guinean Savannah (Adeoye, 1984) that about 4000 kg ha^{-1} dry matter is needed to protect the soil from erosion and to conserve soil water. Substantial amounts of biomass are also needed at the beginning of the farming season to be effective in controlling weeds (Akobundu et al., 2000) and to supply nutrients to the crops.

In a preliminary study at one field in the northern Guinean Savannah of northern Nigeria, Mucuna mulch disappeared at a rate of approximately 1000 kg ha^{-1} $month^{-1}$, resulting in a total loss of 50% of the initial dry matter (Carsky et al., 1998). However, in the more humid derived Savannah of Benin, an additional 1500 and 3000 kg ha^{-1} of *M. cochinchinensis* biomass was accumulated between early December and late March at highly and less degraded sites, respectively. It was concluded that dry matter persistence varies substantially across agroecological zones (Carsky and Eteka, 2000).

1.3. Changes in nutrient composition of Mucuna residues over time

In addition to reducing total biomass, the degradation of leguminous mulch material throughout the dry season also changes its chemical composition with further implications for subsequent crop performance. When *Mucuna aterrima* (Piper et Tracy) Holland residues are left on the soil surface, the N fertilizer replacement value for subsequent maize was only 10–20 kg N ha^{-1} in the subhumid zone of Brazil (Burle et al., 1992) as compared to incorporated *M. aterrima* residues with 50–100 kg N ha^{-1} (Lathwell, 1990). The reduced effect of mulched Mucuna is partly due to N volatilization during the dry season. In a green house trial, only 55% of N applied as surface-placed Mucuna mulch was found in the remaining undecomposed residue or as inorganic N in the soil (Costa et al., 1990).

1.4. Objectives of the study

This study had the following objectives:

(1) to compare two Mucuna varieties differing in length of maturity grown in different cropping systems;
(2) to estimate Mucuna biomass production in farmers' fields in the Forest–Savannah Transitional Zone of West Africa and observe the rate of its disappearance as compared to a short season natural fallow during the dry season, including Mucuna yield components and estimation of changes in nutritional composition of the mulch material;
(3) to estimate the amount and percentage of atmospheric N_2 fixation by a Mucuna fallow in farmers' fields;
(4) to estimate the ground cover provided by various biomass components throughout the dry season on fields planted with Mucuna during the previous minor rainy season.

For this purpose, two Mucuna cultivars were assessed in their respective cropping systems under farmer management in 1999: late maturing *M. pruriens* var. *utilis* relay intercropped in June/July in major season maize and an early maturing Mucuna cultivar grown after maize harvest in August/September (Fig. 1). Prior to this, in 1998, *M. pruriens* was grown as a sole crop after maize harvest to assess Mucuna biomass build-up over time.

2. Materials and methods

2.1. Study sites

The Sunyani district within the Forest–Savannah Transitional Zone of Ghana was the main study area. The district lies between 2°8′ and 2°3′W latitude and between 7°7′ and 7°36′N longitude and falls within Ghana's Wet Semi-Equatorial Climatic Zone (Sunyani

District Assembly, 1995). Rainfall pattern in Sunyani shows a weak bimodal distribution, with the major rainy season between March/April and July. After a short dry period, the minor rainy season starts in September and ends in November (Fig. 1). Annual precipitation is around 1300 mm.

The southern and middle parts of Sunyani district fall into the great soil group locally classified as Forest Ochrosols (Rhodic Ferralsol or Haplic Ferralsol) whilst soils in the northern part are classified as Savannah Ochrosols (Haplic Acrisols) (Brammer, 1962).

Atebubu district, a second minor location of the research activities, is located in the Guinea Savannah Zone with an annual precipitation of about 1100 mm. The bimodal rainfall pattern that extends into the southern parts of Atebubu district changes into a monomodal one in northern Atebubu. *Imperata cylindrica* (L.) Beauv is limiting crop performance in many parts of the district. While soils in southern Atebubu may be classified as Savannah Ochrosols, soils in northern Atebubu are Savannah Ochrosol-Groundwater laterite (Brammer, 1962). Considerably lower organic carbon (C) contents were found in Atebubu than in Sunyani.

2.2. Soil and plant tissue analysis

Twenty core samples were taken from a 0 to 20 cm depth on each farmer's experimental site (combined test and control plot) before planting the Mucuna fallow. Analyses of all soil and plant tissue samples were conducted at the Soil Research Institute in Kumasi. Sub samples were analyzed in the lab for determination of organic C (%), total N (%), pH, P and cation exchange capacity (CEC). Soil organic C was determined by wet oxidation using potassium dichromate. Total N was measured by the standard Kjeldhal technique. Soil pH was determined in a 1:1 soil: water suspension. The available P was estimated using the Bray I method. The CEC was determined by extraction with ammonium acetate. Plant samples were oven dried at 70 °C to a constant weight (48 h) and ground in a stainless steel mill to pass through a 2 mm mesh sieve. Phosphorous was determined in plant ash solution using the vanadomolybdate method. Potassium was determined in plant ash solution by flame photometry. Calcium and magnesium were determined in ash solution using the EDTA titration method. All soil and tissue analytical procedures followed those of the Royal Tropical Institute (1984, 1986).

Table 1
Main top soil characteristics (0–20 cm; ±standard error of the mean) of the on-farm experimental sites

Property	Sunyani	Atebubu
pH (H_2O 1:1)	6.7 ± 0.1	5.9 ± 0.2
organic C (%)	20 ± 1	11 ± 1
Total N (%)	0.05 ± 0.003	0.05 ± 0.005
Available P (mg kg^{-1})	1.8 ± 0.3	8.6 ± 1.7
CEC ($cmol_+ kg^{-1}$)	15.8 ± 1.6	5.0 ± 0.5
Sand (g kg^{-1})	425 ± 19	690 ± 22
Silt (g kg^{-1})	398 ± 14	232 ± 20
Clay (g kg^{-1})	177 ± 29	78 ± 08

A summary of the analytical data for the soils of the on-farm trials is presented in Table 1. Many soils contain abundant gravel or concretionary material that significantly affects their physical properties, particularly their water-holding capacity.

2.3. Selection of farmers and treatments

All data collection was carried out in the framework of an extension project, the Sedentary Farming Systems Project (SFSP), which followed a Participatory Technology Development (PTD) approach. After problem analysis, the formation of interest groups and identification of possible solutions by both farmers and extension workers, farmers chose which technology to test according to their own priorities and needs. Data presented here refer only to farmers who tested Mucuna during the minor season. No incentives were given to farmers except seeds of Mucuna. Fertilizers and other organic amendments were not applied and Mucuna seeds were not inoculated. General guidelines were discussed with farmers like time range for planting, planting distance and management. However, the implementation was fully managed by farmers. The researchers and project team members did all trial measurements. At each farmer's location, only one Mucuna variety was grown during the minor season.

2.4. Experimental plots

Mucuna was tested on 20 m × 20 m test plots with an adjacent control plot of the same size at each farmer's location where maize had been planted during the preceding major rains. In 1998, in Sunyani district, late maturing black seeded *M. pruriens* var. *utilis* was grown on 15 farmers' fields after harvesting major season maize between August and September. In 1999, after participatory reflection on the Mucuna technology between farmers, extension workers and scientists how best to integrate Mucuna varieties of different length of maturity into existing farming systems, *M. pruriens* var. *utilis* was relay-interplanted in between maize rows at tasseling stage or later (June–July) to not compete with the maize crop in 16 farmers fields. Planting of *M. pruriens* was combined with the second weeding of maize. The recommendation for plant spacing was the same as for maize (0.9 m × 0.4 m with two seeds per hill). At the maize harvest only the cobs were removed and the dead maize stalks served as support for the Mucuna cover crop to climb up until the stalks finally collapsed leading to a spreading of Mucuna until the onset of the dry season in November when pod formation and senescence is initiated. Additionally in 1999, a mottled seeded early maturing Mucuna variety was planted in 11 farmers' fields, sole-cropped following harvest of major season maize (cobs removed only) in August/September with the same plant spacing (like *M. pruriens* in 1998 and in 1999). The latter system required intensive weeding prior to planting Mucuna because weeds emerge in large quantities once maize had been harvested. Control plots in all locations were left to natural fallow until the succeeding year's major season maize.

In Atebubu district in the Guinea savannah, *M. pruriens* var. *utilis* was planted in 1999 in 20 farmers fields after a speargrass (*Imperata cylindrica*) fallow. The *Imperata* fallow was slashed or uprooted and Mucuna was planted with the same spacing as in Sunyani district. Planting time was June/July. In Atebubu district farmers were not willing to leave a portion of the natural fallow as a control plot.

In all locations and years, it was recommended to weed 2–4 weeks after planting (WAP), but frequency and quality depended on actual weed pressure and the individual farmer's attitude.

2.5. Mucuna biomass build-up

In 1998, the biomass build-up of *M. pruriens* grown during the minor season rains was investigated in pure stand in Sunyani district. Above-ground Mucuna biomass (excluding weeds and crop residues) was measured at 30, 60 and 90 days after planting (DAP) Mucuna. Three sub samples were randomly taken at each farmer's field using a 1 m × 1 m iron frame. Samples were air dried, weighed and sub samples were taken and weighed again before being submitted to the Soil Research Institute in Kumasi for final dry matter determination. The impacts of planting dates and plant population on the biomass build-up were tested for the different sampling dates.

2.6. Mucuna biomass persistence

Mucuna biomass was also assessed during the 1999/2000 dry season in Sunyani and Atebubu districts. Above-ground biomass of the Mucuna and the natural fallow were estimated at the end of November 1999, which is the onset of the dry season. Two sub samples (1 m^2 each) within each replication of each treatment were extracted. Plant residues were collected and living plant parts were cut at soil surface to estimate total above-ground biomass. During the first sampling in November Mucuna biomass, weeds and crop residue biomass were separately collected and analysed. On the succeeding sampling dates, 8 (January), 12 (February) and 16 weeks (March) after the first sampling, above-ground biomass consisted of Mucuna, weeds, and crop residues combined because it was not possible to distinguish the different fractions anymore. Plant samples were taken, weighed with an electronic scale, and the dry matter determined after drying at 60 °C for 48 h. Below-ground biomass was not included. All dry matter results are expressed in kg DM (dry matter) ha^{-1}.

2.7. Mucuna grain yield characteristics

In February 2000, Mucuna grain yield harvested by farmers was assessed comparing the late maturing *M. pruriens* ($N = 13$) and the early maturing cultivar ($N = 12$). Areas from which the farmers harvested Mucuna seeds was measured to calculate per hectare values. At four farmers' sites for each Mucuna variety, seed and husk samples were taken from each variety to determine dry matter and macronutrient concentrations for seeds and husks seperately, 100 seed weight, and seed/husk ratio. Grain harvest index (GHI) was defined as the ratio of grain mass to total above-ground dry mass. In this study grain yield was related to the above-ground Mucuna dry matter taken in November 1999. N harvest index (NHI) was defined as the ratio of N content in Mucuna seeds to N content in above-ground Mucuna biomass (in November 1999).

2.8. Ground cover

The beaded string method described by Sarrantonio (1991) was applied to estimate the percent ground cover. Four measurements were taken every sampling date on each plot. Data were taken from the same plots and on the same sampling dates as for the biomass sampling in 1999/2000 in Sunyani district.

2.9. Estimation of biologically fixed N

Symbiotically fixed N (NdA = N derived from atmosphere) was estimated by the total N difference method in Sunyani district. The fallow vegetation on the control plot, dominated by *Chromolaena odorata*, was used as reference biomass:

$$\text{NdA}\ (\%) = \frac{\text{TN}_{\text{fix}} - \text{TN}_{\text{ref}}}{\text{TN}_{\text{fix}}} \times 100 \quad (\text{Fosu, 1999})$$

TN_{fix} and TN_{ref} are total N accumulation by N_2 fixing and reference plants, respectively. Atmospheric N_2 fixation was determined during the last week of November 1999 for both Mucuna varieties at all locations. This was done regardless of the planting time because it was assumed to be the peak of the biomass production after which a decline will take place.

2.10. Statistical analysis

Data were analyzed for normal distribution with the Kolmogorov–Smirnov test. Paired-samples *t*-tests were performed if the same farmer tested two treatments or if the same field was compared at two different sampling dates. Independent-samples *t*-test was applied to compare two treatments tested by different farmers. Standard error of the mean difference (S.E.D.) was computed and treatments being significantly different from each other at $P < 0.05$ were indicated by different letters. For data undergoing data transformation prior to statistical analysis, only statistical difference ($P < 0.05$) and standard error of the mean values (S.E.) were calculated.

Percentage data of nutrient concentrations and percentage values of exposed soil surface were transformed using $Y = (X + 0.5)^{1/2}$ where X is the original data and Y the transformed data (Gomez and Gomez, 1984). Values of 0% were substituted by $1/4n$ where n is the sample size of the percentage value. Outliers and extreme values were identified and excluded as missing values prior to further statistical analysis. In the case of nutrient concentrations, they were substituted by sample mean values prior to further calculations for nutrient uptakes. Comparison of experimental parameters and their interdependence were computed by correlation and regression analysis. The equation of the function is accompanied by the coefficient of determination with the number of asterisks indicating the significance level at $P < 0.05$ (*), $P < 0.01$ (**) and $P < 0.001$ (***). Pearson's simple correlation coefficients (r) were computed for nutrient accumulation in Mucuna biomass (combined *M. pruriens* and local Mucuna cultivars) in November 1999 as well as after the dry season in March 2000 and the respective dry matter and nutrient concentration of the mulch material.

3. Results

3.1. Biomass build-up

3.1.1. Biomass accumulation during the short rainy season

In 1998, *M. pruriens* was planted between August 5 and September 24 at the different farmers' locations. Plant population at 30 DAP was between 19,900 and 80,400 ha^{-1}. Biomass build-up of *M. pruriens* was slow in the beginning with only 163 ± 29 kg DM ha^{-1} at 30 DAP and 1472 ± 233 kg DM ha^{-1} at 60 DAP but increased to 4003 ± 1321 kg DM ha^{-1} at 90 DAP. No relationship was found between plant population and Mucuna biomass accumulation or between planting date and *Mucuna* biomass accumulation at any of the sampling dates. During the second experimental year, at the end of the minor season in November 1999, fields planted with *M. pruriens* and the early maturing Mucuna cultivar had built-up 8555 and 8020 kg DM ha^{-1}, respectively, consisting of Mucuna biomass, weeds and crop residues. However, the respective biomass of the natural regrowth on the

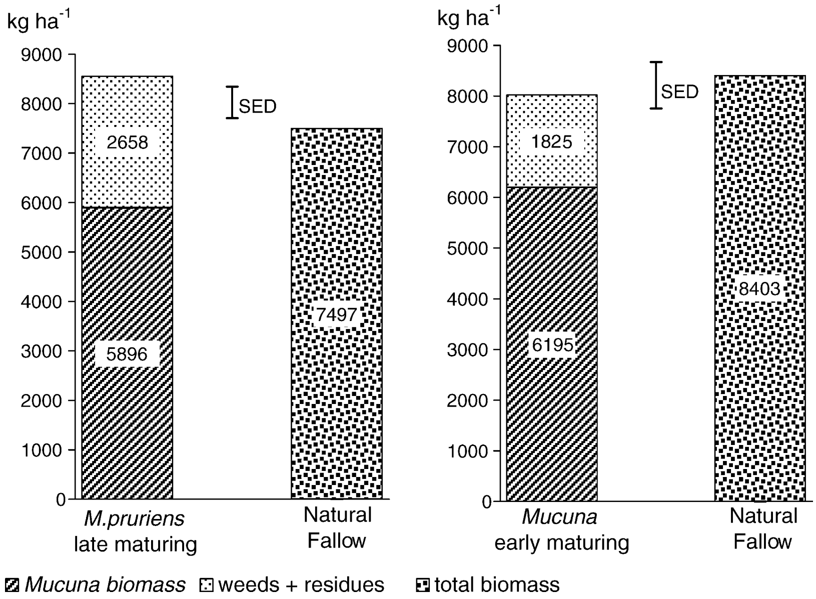

Fig. 2. Above-ground biomass production on farmers' fields planted with either late maturing *M. pruriens* or with an early maturing Mucuna cultivar and their corresponding short season natural fallow of the same duration.

control plots was 7497 and 8403 kg DM ha^{-1}, which was not significantly different from the Mucuna plots (Fig. 2).

3.1.2. Mucuna grain yield

Mucuna yield assessment revealed significantly higher grain yields for the early maturing cultivar at 1299 ± 90 kg ha^{-1}, 62% more than the yield of *M. pruriens* at 804 ± 87 kg ha^{-1}. The grain harvest index and the N harvest index were also higher for the early maturing Mucuna cultivar compared to *M. pruriens* (Table 2).

3.2. Atmospheric N_2 fixation by Mucuna

M. pruriens symbiotically fixed 107.7 kg N ha^{-1} with values ranging from 46.1 to 170.7 kg ha^{-1} (Table 3). On average, 57.8% of the assimilated N was derived from the atmosphere. The early maturing Mucuna cultivar was able to fix only 46.1 kg N ha^{-1} on average, representing 22.6% of N uptake. Significant correlation was observed between the amount of symbiotically fixed N and the Mucuna biomass produced at the end of November with $R^2 = 0.69$ for *M. pruriens* and $R^2 = 0.75$ for the local Mucuna cultivar (Fig. 3).

Table 2
Mucuna seed yield and nutrient content (±standard error) of two varieties grown in different cropping systems

	Late maturing *M. pruriens*	Early maturing *Mucuna* spp.
Grain[a]		
Yield (kg ha^{-1})	804 ± 87	1299 ± 90
100 seed weight	73.8 ± 4.4	102.1 ± 1.2
N (%)	3.76 ± 0.17	3.31 ± 0.06
P (%)	0.04 ± 0.01	0.17 ± 0.09
K (%)	0.94 ± 0.27	0.85 ± 0.21
Ca (%)	0.59 ± 0.11	0.48 ± 0.06
Mg (%)	0.49 ± 0.13	0.39 ± 0.03
Husk		
Yield (kg ha^{-1})	503 ± 55	669 ± 47
N (%)	0.34 ± 0.08	0.43 ± 0.06
P (%)	0.20 ± 0.08	0.28 ± 0.08
K (%)	1.18 ± 0.19	1.01 ± 0.11
Ca (%)	0.94 ± 0.07	1.34 ± 0.05
Mg (%)	0.49 ± 0.01	0.62 ± 0.07
Grain/husk ratio	1.6 ± 0.1	1.9 ± 0.1
Grain harvest index	14.0 ± 1.3	24.6 ± 3.9
N harvest index	24.8 ± 2.3	30.6 ± 3.1

[a] Grain yield were evaluated on 25 farmers' plots, other components on four farmers' plots for each variety.

Table 3
Estimated amount and percentage of N_2 fixed by the total N difference method in two Mucuna varieties

		kg N ha^{-1} fixed	%NdA
M. pruriens	Mean	107.7 (46.1–170.7) a	57.8 a
(Late maturing)	S.E.	10.2	3.9
Mucuna spp.	Mean	46.1 (0–116) b	22.6 b
(Early maturing)	S.E.	12.5	6.0
	S.E.D.	16.2	7.1

Columns containing the same letter are not significantly different at $P < 0.05$.

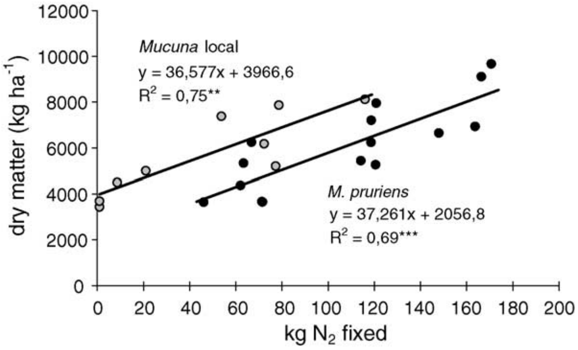

Fig. 3. Relationship between amount of symbiotically fixed N_2 and Mucuna biomass produced at the end of November 1999 in Sunyani district.

3.3. Above-ground biomass persistence

During the dry season between November and March, the above-ground biomass on the Mucuna plots decreased consistently for both cultivars. Relay-intercropped *M. pruriens* plots lost only 23% of its initial biomass throughout the dry season while on the early maturing cultivar's plots biomass declined by 45%. In a linear regression model, above-ground biomass on *M. pruriens* plots was reduced by 503 kg DM ha^{-1} every 4 weeks ($R^2 = 0.93$), while on plots planted with the early maturing Mucuna cultivar the total above-ground biomass declined at a rate of 911 kg DM ha^{-1} ($R^2 = 0.97$). Applying a quadratic regression model resulted in higher R^2 values but the prediction for the biomass decline on the early maturing Mucuna plots had an error probability of 12% (Fig. 4). The corresponding biomass of the natural fallow plots also declined until February but increased again in March with the onset of the rains.

3.4. Estimated ground coverage during the dry season

In November of 1999 (initial sampling), ground cover by live plant parts for both Mucuna cultivars was greater than 70% and cover by dead plant litter ranged between 20 and 30%, with no measurable bare soil, thus combined live and dead plant material gave 100% ground coverage (Fig. 5). By January, 8 weeks after initial sampling (WAIS) almost all living plant parts

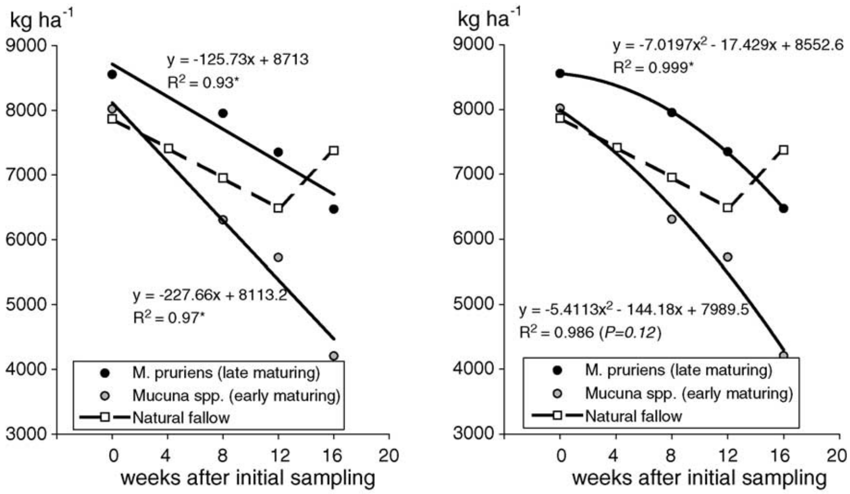

Fig. 4. Persistence of total above-ground biomass on plots planted with *Mucuna pruriens*, an early maturing Mucuna cultivar and a short season natural fallow during the dry season in Sunyani district.

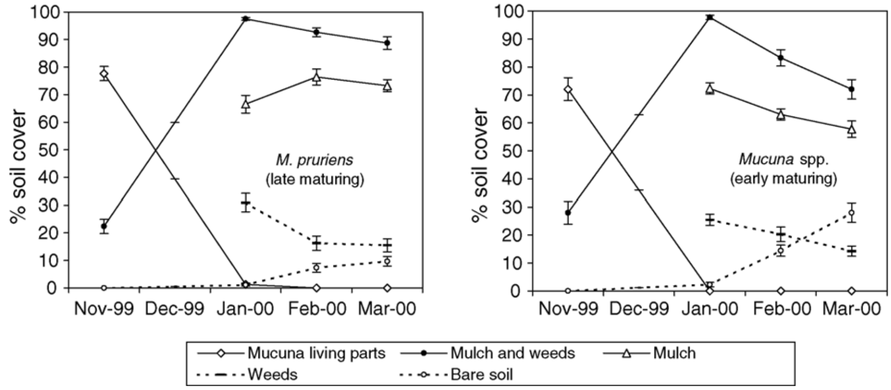

Fig. 5. Ground cover on *Mucuna pruriens* plots or plots planted with the early maturing Mucuna cultivar during the dry season in Sunyani district; error bars represent standard error of the mean.

had died back and, as a consequence, dead mulch litter had accumulated to cover 66.6 and 72.3% of the soil in *M. pruriens* and the early maturing variety Mucuna plots, respectively. Together with appearing weeds, there was more than 97% soil cover in both treatments. Ground coverage declined from 97.5 to 88.8% between January (8 WAIS) and March (16 WAIS) in *M. pruriens* plots and from 97.7 to 72.0% in plots planted with the early maturing cultivar. This decline was associated with a more rapid increase in percent soil exposed in the early maturing Mucuna plots as compared to *M. pruriens* plots (Fig. 6). While in January (8 WAIS) less than 2.5% of the soil was exposed in plots of the two Mucuna cultivars, by February (12 WAIS) the percent of exposed soil in early maturing Mucuna cultivar plots was twice that of the *M. pruriens* plots, and in March (16 WAIS) the percentage was three times that of the *M. pruriens* plots.

Total soil coverage by any type of biomass showed a significant positive correlation to the total biomass in *M. pruriens* fields ($r = 0.98$) but for the early maturing cultivar the correlation ($r = 0.92$) had an error probability of 7.8%.

3.5. Changes in nutrient composition of mulch material during the November–March dry season

In November, at the beginning of the dry season, significantly more N was accumulated in the total above-ground biomass on the plots of both Mucuna fallow cultivars than in the total above-ground biomass of their respective natural fallow control plots. Differences in accumulation of other macronutrients (P, K, Ca and Mg) were small and not significant. The higher N content of the total above-ground biomass on Mucuna plots was a result of much higher N concentrations in the Mucuna biomass fractions, 2.5 and 2.6% of *M. pruriens* and early

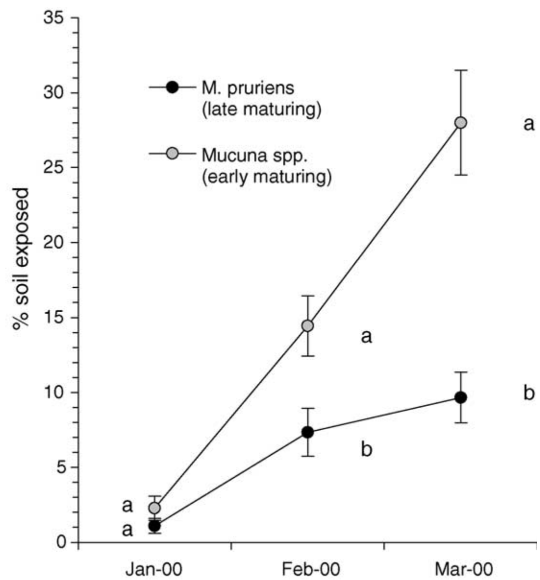

Fig. 6. Percentage of soil surface not covered by biomass particles on late maturing M. pruriens plots and on early maturing Mucuna plots. Data points of the same sampling date containing different letters are significantly different at $P < 0.05$. Error bars represent standard errors of the means.

Table 4
Nutrient concentration (%) in total above-ground biomass on plots planted with late maturing *M. pruriens*, on plots with an early maturing Mucuna cultivar and on plots of a short season natural fallow in Sunyani district in November 1999

Treatment		N	P	K	Ca	Mg
Mucuna pruriens	Mean	2.5 a	0.2 a	1.3 a	2.0 a	0.9 a
(Late maturing)	S.E.	±0.07	±0.01	±0.05	±0.12	±0.11
Mucuna spp.	Mean	2.6 a	0.2 a	1.4 a	2.2 a	0.9 a
(Early maturino)	S.E.	±0.05	±0.01	±0.04	±0.12	±0.10
Natural fallow	Mean	1.3 b	0.2 a	1.7 a	2.0 a	1.0 a
	S.E.	±0.11	±0.01	±0.18	±0.09	±0.09

Columns containing the same letter are not significantly different at $P < 0.05$.

Table 5
Nutrient concentration (%) in total above-ground biomass on plots planted with late maturing *M. pruriens*, on plots with an early maturing Mucuna cultivar and on plots of a short season natural fallow in Sunyani district in March 2000

Treatment		N	P	K	Ca	Mg
M. pruriens	Mean	1.3 a	0.01 a	0.9 a	1.3 a	0.5 a
(Late maturino)	S.E.	±0.04	±0.002	±0.06	±0.06	±0.05
*Mucuna*spp.	Mean	1.3 a	0.01 a	0.8 a	1.4 a	0.6 a
(Early maturino)	S.E.	±0.10	±0.001	±0.08	±0.09	±0.06
Natural fallow	Mean	1.0 b	0.01 a	0.8 a	1.2 a	0.5 a
	S.E.	±0.01	±0.001	±0.03	±0.08	±0.04

Columns containing the same letter are not significantly different at $P < 0.05$.

maturing Mucuna cultivar biomass, respectively (Table 4).

In March, N concentration of the total biomass on Mucuna plots had declined by about half, but at 1.3% was still significantly higher than on natural fallow plots at 1.0% (Table 5). There was also a significant decline in the concentrations of the other macronutrients from November to March. The reduced nutrient

Table 6
Nutrient content of total above-ground biomass in kg ha^{-1} on Mucuna and short natural fallow plots in November 1999 and March 2000 in the Sunyani district

	N	P	K	Ca	Mg
November 1999					
M. pruriens(late maturing)	183.6 a	16.2 a	109.2 a	152.9 a	73.1 a
Natural fallow	76.0 b	14.7 a	125.0 a	147.5 a	71.8 a
S.E.D.	10.2	1.3	15.1	12.5	8.7
Mucuna spp. (early maturing)	183.1 a	14.5 a	115.9 a	158.4 a	76.8 a
Natural fallow	140.0 b	15.8 a	126.7 a	155.4 a	65.0 a
S.E.D.	13.7	1.3	20.6	19.2	20.0
March 2000					
M. pruriens (late maturing)	85.2 a	0.78 a	56.8 a	88.2 a	33.3 a
Natural fallow	57.0 b	0.57 b	56.7 a	81.8 a	33.2 a
S.E.D.	6.8	0.10	4.7	10.9	5.9
Mucuna (early maturing)	55.4 a	0.39 a	37.2 a	65.2 a	23.4 a
Natural fallow	101.4 b	0.61 a	73.0 b	109.4 b	39.5 a
S.E.D.	8.6	0.10	4.7	10.9	5.9

Columns containing the same letter per field are not significantly different at $P < 0.05$.

Table 7
Pearson's simple correlation coefficients (r) relating nutrient content in Mucuna biomass with the dry matter and nutrient concentration of the mulch material

	N	P	K	Ca	Mg
Dry matter November	0.95**	0.81**	0.91**	0.81**	0.59**
Percentage nutrient concentration November	0.59**	0.46*	−0.13 n.s.	0.71**	0.83**
Dry matter March	0.87**	0.31**	0.71**	0.84**	0.65**
Percentage nutrient concentration March	0.30 n.s.	0.85**	0.54**	0.42**	0.63**

n.s: Not significant. Significant correlation coefficients are indicated as follows.
* $P < 0.05$.
** $P < 0.01$.

Table 8
Total above-ground biomass (DM in kg ha^{-1}) and nutrient content in *M. pruriens* plots in November 1999 and March 2000 in the Atebubu district

	DM (kg ha^{-1})	N	P	K	Ca	Mg
November 1999	6107 a	99.6 a	10.9 a	60.3 a	95.1 a	60.4 a
March 2000	4565 b	14.4 b	4.6 b	16.3 b	82.3 b	33.2 b
S.E.D.	789	11.3	2.3	6.6	15.9	19.2

Columns containing the same letter are not significantly different at $P < 0.05$.

Table 9
Nutrient concentration (%) in above-ground *M. pruriens* biomass at the beginning (November 1999) and the end (November 2000) of the dry season in the Atebubu district

		N	P	K	Ca	Mg
November 1999	Mean	1.5 a	0.2 a	1.0 a	1.6 a	1.0 a
($N = 20$)	S.E.	±0.08	±0.02	±0.06	±0.13	±0.04
March 2000	Mean	0.3 b	0.1 b	0.4 b	2.0 b	0.7 b
($N = 12$)	S.E.	±0.02	±0.01	±0.05	±0.09	±0.06

Columns containing the same letter are not significantly different at $P < 0.05$.

concentrations together with the decline in total biomass resulted in significantly lower nutrient content for the above-ground biomass on Mucuna plots in March compared to November (Table 6). While in March nutrient content in the mulch of *M. pruriens* plots was equal to or higher than the nutrient content in their respective fallow control treatment, the nutrient content of the mulch in the early maturing Mucuna cultivar plots was lower than the nutrient content of the biomass in the natural fallow plots. Both Mucuna biomass and nutrient concentration in *Mucuna* correlate to nutrient content, however, biomass showed the strongest correlation (Table 7).

In the Atebubu district in the Guinea Savannah Zone, total above-ground biomass on sole cropped *M. pruriens* fields in November was 6107 kg DM ha^{-1}. At the end of the dry season in March 4565 kg DM ha^{-1} remained (Table 8). The decline in macronutrient content in the biomass of *Mucuna* plots from November to March (Table 9) was associated with a significant decrease in all macronutrient concentrations except for Ca, which increased during the same period from 1.6 to 2% (Table 9).

4. Discussion

4.1. Biomass accumulation

4.1.1. Biomass accumulation as influenced by the cropping system

Although it has been shown that intercropping of *M. pruriens* with a cereal reduces the Mucuna's maximum biomass potential (Sanginga et al., 1996;

Fischler, 1996), little direct competition between Mucuna and maize is expected when the Mucuna is planted after maize tasseling. This is due to Mucuna's slow initial growth and development as compared to many grass species. Similarly, it has been found that *Cajanus cajan* (L.) Huth late relay intercropped with maize had no negative effect on maize performance or on the biomass build-up of *Cajanus* (Dalal, 1974). Late relay intercropping in major season maize allows the green manure to establish before the dry spell in August (Fig. 1). Its main growth period, however, is during the minor season rains. Therefore, it is not surprising that total biomass production on plots of *M. pruriens* (8555 kg DM ha^{-1}) relay intercropped into major season maize and allowed to grow during the minor season rains was equal to or greater than biomass on plots of the early maturing Mucuna variety (8020 kg DM ha^{-1}) planted after the dry spell with the first rains in late August/September with no significant difference found between the two (S.E.D. = 871 kg DM ha^{-1}; Fig. 2). To plant early maturing Mucuna cultivars as a relay intercrop in June does not appear to be feasible. Seed production and subsequent senescence would occur during the minor season rains, leading to accelerated biomass degradation and re-infestation by weeds.

4.1.2. Probable underestimation of actual biomass accumulation

Maximum biomass production was assessed during the flowering stage for both of the Mucuna cultivars regardless of planting time. The dense cover formed by a creeping legume like Mucuna leads to self-shading and senescence of leaves, resulting in a dense mat of organic matter (Giller et al., 1997). Therefore, the total biomass contribution may be significantly underestimated in the current study, since data did not include litter fall during the growing period. In Indonesia, Mucuna leaf fall over 6 months contained 40 kg N ha^{-1} and was almost equivalent in mass to the live shoots of the plant (van Noordwijk and Purnomisid, 1992). Significant N benefits in yields of subsequent crops have been reported even when Mucuna was burned (Vine, 1953), suggesting that considerable amounts of N were contributed to the soil from roots and fallen leaves (Giller et al., 1997). Time of sowing Mucuna was not correlated with the maximum biomass production for either cultivar due to other more influential factors such as weed management.

4.1.3. Variations in biomass production

There was a significant difference in biomass production of *M. pruriens* in 1998 (90 DAS) and 1999 with 4003 kg DM ha^{-1} and 6018 kg DM ha^{-1} (exclusive weeds and crop residues), respectively. Variations in rainfall pattern may have been a factor causing the difference in biomass accumulation (Fig. 1). While in 1998 the minor season rains stopped immediately after October, in 1999 they continued longer, with 86.5 mm precipitation in November. Another study in the Savannah of Benin reported significant differences in Mucuna shoot dry weight for two different years at the same location (Houngnandan, 2000). Therefore, a high variation of biomass production between years, between different agroecological zones, and even between farm plots has to be expected, due at least in part to differences in amount and distribution of rainfall.

4.2. Grain yield

Although *M. pruriens* was grown as a relay intercrop in this study it produced significantly lower seed yields with 804 kg ha^{-1} as compared to the sole cropped early maturing Mucuna cultivar with only 1299 kg ha^{-1}. This stays in contrast to findings of Kachelriess and Tarawali (1994), who found that seed yields of climbing legumes like Mucuna can be increased at least five times by trellising. Calegari et al. (1993), also recommended trellising Mucuna with maize or wooden stalks to increase the seed yield. However, in this study, *M. pruriens* was late relay interplanted into maize in order to reduce the competitive effect with the food crop. At the time when flowers were initiated the remaining dead maize stalks had been fallen down or were purposely bent down to allow an even spread of the Mucuna biomass. Therefore, no effect by trellising on Mucuna seed yield could be expected. The yield data for both systems and varieties rather reflect the seed yield potential of Mucuna when grown on the surface without support.

4.3. N_2 fixation

Estimations of atmospheric N_2 fixation (NdA) in this study (Table 3) were similar to those obtained from on-station trials in Northern Ghana, where late maturing *M. pruriens* was able to fix 103.2 kg N ha^{-1}, 77.3% of the total N up take by the plants. However, no fertilizers were applied in our study while in the on-station trials, *M. pruriens* had received an initial dressing of 17 kg P and 33 kg K ha^{-1} in the form of triple super phosphate (TSP) and muriate of potash, respectively (Fosu, 1999). On farmers' fields in the derived Savannah of Benin, *M. pruriens* had accumulated 25–130 kg N ha^{-1} and 31–177 kg N ha^{-1} at 12 and 20 weeks after planting (WAP), respectively, without application of mineral fertilizer or inoculation with effective rhizobia. Average N_2 fixed in all farmers' fields was 60 kg ha^{-1} at 20 WAP, representing 55% of total N (Houngnandan, 2000). The lower total N_2 fixed and the lower percentage of NdA of the early maturing Mucuna cultivar in our study are likely due to its shorter growing period as compared to that of the late maturing *M. pruriens* which was planted earlier in the cropping cycle. For soybean, it has been shown that early maturing varieties initiate N_2 fixation sooner and terminate sooner than later maturing varieties (Hardy et al., 1973). The delayed exponential phase of later maturing varieties allows them to fix up to twice as much N_2 as early maturing varieties (Havelka et al., 1982). The amount of N accumulated by a legume is generally determined in the short term by its rate of establishment and productivity and the length of the growing period (Giller et al., 1997). A time of harvest effect was also observed in the derived Savannah of Benin where *M. pruriens* harvested 20 WAP acquired, on average, 12% more N_2 from biological N_2 fixation than plants harvested at 12 WAP (Houngnandan, 2000). The much higher difference in N_2 fixation between the two cultivars found in our study indicates a combined effect of harvest time and cultivar.

Average N_2 fixation rates in this study with 108 and 46 kg N ha^{-1} in the late maturing *M. pruriens* relay intercrop system and the early maturing Mucuna sole crop system, respectively, (Table 3) were still relatively high despite low soil P values. However, the wide variation in N_2 fixation in our study from 0 to 171 kg ha^{-1} and other research (Sanginga et al., 1996; Houngnandan, 2000) indicates a considerable risk of technology failure. Application of phosphorous fertilizer to the legume would both considerably raise the portion of NdA and reduce the risk of failure, as P is known to have an important positive effect on N_2 fixation (Idris et al., 1989).

4.4. Soil cover in the dry season

In the subhumid tropics, lowering soil temperature and conserving soil moisture by mulching are beneficial for crop establishment. Unexpected drought may affect seedling growth while excessively high temperatures can result in low emergence rates, stunted growth, insufficient root development and low yield (Harrison-Murray and Lal, 1979). About 4000 kg DM ha^{-1} is needed in the Forest–Savannah Transitional Zone to protect the soil from erosion and to conserve soil moisture (De Vleeschauwer et al., 1980). In 1999, with favorable weather conditions and rains lasting into November (Fig. 1), this threshold was exceeded by both *Mucuna* varieties at both locations. However, in 1998, with rains ending in late October, the biomass of *M. pruriens* grown only during the minor season averaged just below the threshold value of 4000 kg DM ha^{-1}. Based on these observations, a Mucuna fallow grown only during the minor season from September onwards under unfavorable weather conditions is not likely to persist in sufficient quantities throughout the dry season.

4.5. Total above-ground biomass persistence during the dry season

4.5.1. Possible factors affecting biomass persistence on plots of the two Mucuna cultivars

As plant residues decompose, the mulching effect on soil temperature and soil moisture declines (Tian et al., 1993). A plant residue quality index (PRQI) was developed for the subhumid tropics and is negatively correlated to the duration of plant residue effect on soil temperature and soil moisture (Tian et al., 1995). Herbaceous species appear to have a higher PRQI than many woody species, while crop residues like maize straw have lower values than herbaceous and most woody species (Tian et al., 1995). Compared to leaf prunings of woody species, shoots of cover crops seem to have low variability in PRQI among species (Tian and Kang, 1998). With a C/N ratio of 7.5, a lignin concentration of 16.8%, and a polyphenol concentration of 4% (Tian et al., 1992), Mucuna leaves have a PRQI of 9.0 (Tian et al., 1995), indicating a fast decomposition rate and a low persistence. Therefore, a rapid decline in biomass during the dry season was expected on plots planted to both Mucuna cultivars in our study. However, the total above-ground biomass on plots of the two Mucuna varieties declined at different rates. Applying a linear regression model, it was found that in Sunyani, the average biomass losses every 28 days were 503 kg DM ha^{-1} (5.9% of initial biomass) on *M.pruriens* plots and 911 kg DM ha^{-1} (11.4% of initial biomass) on plots of the early maturing variety (Fig. 4). At the end of the dry season, 6471 kg DM ha^{-1} remained on *M. pruriens* plots while only 4206 kg DM ha^{-1} remained on plots planted with the early maturing Mucuna cultivars, just above the threshold requirement of 4000 kg DM ha^{-1}. Differences in loss of total above-ground dry matter between late and early maturing *Mucuna* varieties were also observed by Carsky and Eteka (2000) in the Guinean Savannah of Benin. Subsequent loss of dry matter after seed harvest of long duration varieties (*M. pruriens* var. *utilis*, *M. pruriens* var. Preta and *M. cochinchinensis*) from late January to late April averaged 420 kg DM ha^{-1} while dry matter of the short duration *M. pruriens* var. Rajada declined by 1010 kg DM ha^{-1}.

The difference in biomass persistence between the two Mucuna cultivars in our study can only be partially explained by the different grain yields. Although, on *M. pruriens* plots, 1307 kg DM ha^{-1} (804 kg seeds + 503 kg husks) were removed as part of the total biomass and 1968 kg DM ha^{-1} (1299 kg seeds + 669 kg husks) were removed on plots of the early maturing cultivar, the impact of seed yield on biomass decline was weak and not significant (Fig. 7).

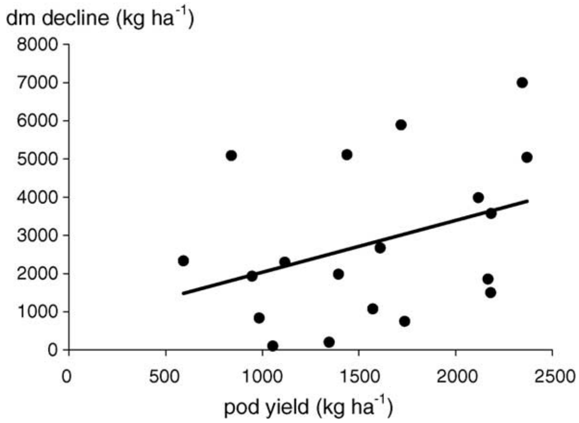

Fig. 7. Relationship between removed Mucuna (both late maturing *M. pruriens* and early maturing Mucuna) yield components and dry matter decline (kg ha^{-1}) from November 1999 to March 2000 in Sunyani. Regression was not significant at $P < 0.05$.

Carsky and Eteka (2000) observed that the greatest decline in Mucuna biomass in the Guinea Savannah occurred between December and January when seed was harvested. Similar to the results of our study, the decline in dry matter after seed harvest was lower for the late varieties (*M. pruriens* var. *utilis*, *M. pruriens* var. Preta, *M. cochinchinensis*) than for the early maturing *M. pruriens* var. Rajada.

Therefore, other factors must be influencing biomass persistence. Plant residue quality index data has only been taken for the leaves of Mucuna (Tian et al., 1995). This PRQI does not appear to be a valuable tool for predicting the persistence of plant material of varying age during the dry season; it is more useful in cases where plant material is directly applied to crops. Because the stems and non-leaf parts of late maturing varieties of Mucuna are likely to be more lignified than those of early maturing varieties, it is suggested that PRQIs need to be investigated for total above-ground biomass (including leaves, stems, weeds and crop residues) after seed harvest.

In the derived Savannah of Benin, it was found that total biomass on plots of *M. cochinchinensis* increased during the dry season (Carsky and Eteka, 2000). We did not detect a similar increase with the Mucuna species used in our study. After the senescence of the Mucuna cover crop, it is difficult to distinguish between Mucuna and other plant parts. If only total above-ground dry matter is measured, occasional rains during the dry season may contribute to weed emergence which can constitute a considerable part of the biomass towards the end of the dry season, especially where Mucuna was not able to control weeds well during the previous minor season. An annual plant such as *M. pruriens* is not able to build-up additional biomass after seed production and senescence, which usually occurs in December/January. However, reestablishment from matured seeds when not harvested appears to be possible if sufficient rainfall events occur during the dry season. In addition, perennial cultivars like *M. cochinchinensis* are able to develop an extensive root system up to 180–240 cm into the soil profile (Anonymous, 1997). It has been reported that their rootstock has the ability to survive the dry season and reestablishes with the first rains (Chikoye and Ekeleme, 2001).

In the Guinean Savannah Zone (Atebubu), results from the current study of *M. pruriens* biomass persistence, with average total above-ground dry matter losses of 386 kg DM ha^{-1} (6.3% of initial biomass) every 4 weeks, were similar to those obtained by Carsky and Eteka (2000), who observed losses of 400 kg DM ha^{-1} (6.4% of initial biomass) every 4 weeks in the same agro-ecological zone for late maturing Mucuna varieties. However, many of the experimental plots in Atebubu were re-infested with speargrass (*Imperata cylindrica* (L.) Beauv.), leading to the suggestion that if it had been possible to measure only the Mucuna residue, the actual percent of Mucuna mulch lost would be much higher.

4.5.2. Biomass persistence on natural fallow control plots compared to Mucuna fallow plots

The decline in above-ground dry matter of the natural fallow control plots was lower from November 1999 to February 2000 (12 WAIS) than was the case for plots of either of the two Mucuna cultivars, presumably because the natural vegetation did not completely die back (Fig. 4). In March (16 WAIS), natural fallow biomass had increased significantly with the onset of the first rains, which stimulated fallow plant growth. In contrast, the dead mulch layer on the Mucuna plots became increasingly more vulnerable over time to decomposition, especially with the increased incidence of rain in March, suggesting a quadratic regression model for the decline of total above-ground biomass throughout the dry season (Fig. 5).

4.5.3. Effect of the difference in the biomass persistence of the two Mucuna cultivars on soil cover

The differences in the biomass persistence are also reflected in the percentage of soil unprotected by any type of biomass. While *M. pruriens* plots retained more than 90% cover at the end of March (16 WAIS), soil of plots planted with the early maturing Mucuna cultivar was less than 75% covered, presumably leaving the soil susceptible to the influence of heat and heavy rains (Fig. 5). Since *M. pruriens* and the early maturing Mucuna cultivar completely died back after December, an increase was observed in weed growth from February (12 WAIS) to March (16 WAIS) which resulted in an increase in the total above-ground dry matter. Fortunately, these weeds usually do not become lignified before the onset of the major season rains due to the short growing period. Therefore, the farmer can easily slash the weed biomass and is not forced to burn before land preparation as is often necessary when fallow vegetation is about 6 months or older, leading to substantial nutrient losses (Slaats, 1995).

4.6. Nutrient composition of fallow biomass

4.6.1. Macronutrient accumulation in biomass of the different fallow plots

Comparisons between Mucuna and natural fallow biomass and their macronutrient accumulation (Table 6) show that N was the only element that increased by changing to a Mucuna fallow. Nutrient content in Mucuna biomass was significantly correlated to nutrient concentration and total biomass, but total biomass was the more important factor for most nutrients (Table 7). In the Guinean Savannah Zone of Ghana, it was found that N content of five cover crops, including *M. pruriens,* depended on dry matter production, as percentage N content was similar for all cover crops tested (Fosu, 1999). Similar results were obtained in this study. There were no significant differences in nutrient concentrations between the two Mucuna cultivars at any sampling date (Tables 4 and 5). Significant differences only existed between the lower N concentrations in the natural fallow biomass compared to the concentrations in Mucuna biomass at both sampling dates although the difference was less pronounced at the end of the dry season. These results suggest that the major advantage of a Mucuna fallow is based on the option of not having to burn vegetation in preparation for the next cropping season because the native vegetation is suppressed and the few emerging weeds could easily be slashed without burning at the beginning of the maize planting season. As a consequence, the total annual nutrient budget in the *M. pruriens*/maize sytem was estimated to be +26 kg N, −9 kg P, −28 kg K, −29 kg Ca and −16 kg Mg in the study area while that of the slash and burn system with short season natural fallow followed by maize was estimated at −120 kg N, −8 kg P, −101 kg K, −93 kg Ca and −36 kg Mg (Anthofer and Kroschel, 2002).

4.6.2. Changes in nutrient content of mulch material over the dry season

Concentrations of all macronutrients measured declined between November and March in all of the biomass components (Mucuna, weeds, crop residues), indicative of the decomposition process. Under laboratory conditions, Tian et al. (1992) found that the leaves of *M. pruriens* released N rapidly, that N release in Mucuna was correlated with calcium release, and that decomposition of the leaves was associated with increased levels of exchangeable calcium and magnesium in the soil. In the present study, N content of Mucuna biomass declined by 54 and 70% between November and March for *M. pruriens* and the early maturing cultivar, respectively. Some of the N may have been lost through volatilization (Glasener and Palm, 1995) or through leaching beyond the rooting zone of succeeding crops (Hagedorn et al., 1997) and only a portion remains available in the soil for succeeding crop growth. The less rapid decline in N content (Table 6) and total biomass (Fig. 4) of the late maturing *M. pruriens* is suggested to be due to differences in the chemical composition of the plant material. Because of its longer life span, *M. pruriens* presumably developed more lignin rich stems, which may have slowed down decomposition and N release. It is well established that C/N ratios, lignin content, and lignin/N ratios are related to plant residue decomposition rates and N mineralization patterns, with higher ratios or contents slowing down decomposition as a result of initial N immobilization (Mellilo et al., 1982; Mellilo and Aber, 1984; Frankenberger and Abdelmagid, 1985; Anthofer et al., 1997). Different parts of leguminous plants vary substantially in their chemical characteristics (Anthofer et al., 1997).

4.7. Other factors affecting agronomic potential and adoption of Mucuna fallows

4.7.1. Weeding

The slow build-up of Mucuna biomass during the first 2 months highlights the need to weed after planting. While this is essential for early maturing varieties planted after maize harvest in August/September, late maturing Mucuna varieties relay planted into major season maize in June often require no further weeding after planting. This is because (1) weeding prior to planting of Mucuna in the existing maize crop can be combined with the second weeding of maize, and (2) since maize has formed a canopy at that time, emerging weeds do not seriously compete with Mucuna seedlings, which begin to climb up the maize stalks. Reduced effort for weeding makes Mucuna intercropping economically more attractive in addition to the better persistence of its biomass throughout the dry season.

4.7.2. Available labor

Planting *M. pruriens* in June also fits well into the labor calendar of the farmers. In June, the workload is relatively low and the time required for planting is available. During this month, the highest precipitation is observed (Fig. 1) which makes planting less risk prone and enables the establishment of a good root system ahead of the dry spell in August. However, the situation is different for early maturing varieties of Mucuna planted like a minor season food crop in August/September. In Sunyani, this is when farmers are engaged in harvesting major season maize and in land preparation for planting minor season food crops with the first rains. Planting Mucuna at this time results in serious competition with other important farming activities (Anthofer, 2000) or leads to a delay in planting of the Mucuna fallow which can reduce its agronomic potential and consequently its chances of adoption.

5. Conclusions

This work focused on the build-up of Mucuna as a cover crop during the minor rainy season and the persistence of total above-ground biomass on Mucuna plots during the dry season, focusing on two maize/Mucuna systems (Mucuna late relay intercropped into major season maize and Mucuna minor season sole crop) in the Forest–Savannah Transitional Zone of Ghana. Late maturing Mucuna varieties can more easily be integrated into existing farming systems than early maturing ones planted in August/September because Mucuna planting does not compete with other farming activities but can be combined with the second weeding of maize. Moreover, late maturing varieties when relay intercropped into maize in June are able to fix more N before the onset of the dry season than early maturing Mucuna varieties planted sole cropped in August/September. In addition, the total accumulated above-ground biomass on late maturing Mucuna plots is less sensitive to degradation during the dry season providing a better protection for the soil. However, above-ground biomass production and nutrient uptake of the Mucuna fallows as compared to a short season natural fallow did not differ except in terms of higher N accumulation.

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